Real-Time Forecasting System of Winds, Waves and Surge in Tropical Cyclones

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LONG-TERM GOALS

The long-term goal of this partnership is to establish an operational forecasting system of the wind field and resulting waves and surge impacting the coastline during the approach and landfall of tropical cyclones. The results of this forecasting system would provide real-time information to the National

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Hurricane Center during the tropical cyclone season in the Atlantic for establishing improved advisories for the general public and federal agencies including military and civil emergency response teams.

OBJECTIVES

1) To define output products necessary to enhance the guidance skills of the Tropical Cyclone Forecast/Advisory product.
2) To test the model infra-structure that would lead toward better forecast information for landfall hurricane wind, wave, and surge conditions. Several historical storms will be used to assess model infra-structure.
3) To develop the interface that couples high-resolution cyclone wind fields to the selected wind model.
4) To develop a system that couples storm surge and spectral wave models driven by winds specified in 6).
5) Test entire system via a proof-of-concepts approach with data from several historical hurricanes.
6) Test system in semi-operational mode during several hurricane seasons and begin transition to fully operational mode.

APPROACH

During this hurricane season we have been testing a proto-type model system for forecasting winds, waves and surge in real time in a pre-operational mode. The focus of the project effort was to implement a fully automated, operational model forecasting system that is capable to download input data (Hwind from NOAA/AOML) for initializing the wind fields as well as all in-situ buoy station and satellite data to generate wind fields for a five day forecast. The real-time fields of forecasted wind and pressure variables were applied as forcing fields in wave and hydro-dynamical (storm surge) models. The model computations were completed within 60 minutes and the entire cycle was repeated every six hours to simulate the advisory cycle of the National Hurricane Center.
A project approach was described in previous reports.

WORK COMPLETED

1. Completed this extremely active hurricane season in fully automated, operational mode. Even the currently last tropical storm ZETA is modeled.
2. The WINDGEN system continued to perform excellent during this extremely active hurricane season with many super-type hurricanes. The system is ready for operational use and we have tested a higher resolution grid covering the entire area at 10 km and 15 minute intervals.
3. Wave and surge models have been coupled to include the effect of momentum input (radiation stress) from breaking waves on sea-level rise in coastal regions.
4. Tidal dynamics are fully integrated into the surge predictions.
5. Surge model is fully integrated into forecast system to run in real-time.
6. We have added alternate track forecasts (currently about six) to the computational cycle. Current limitations to include more tracks for ensemble predictions are insufficient computer resources.
7. We have completed several improvements to graphical formats and posting to website (http://hurricanewaves.org)
8. Finally, from about September on we made NOPP forecast products accessible and available to the National Hurricane Center for evaluation.

RESULTS

Wind Field Generation Program:

The WINDGEN program is in its third iteration and has been successfully applied during the 2005 hurricane season. All required real time acquisitions of track, H*WIND snapshots, background fields from NCEP and alternate track information required by the WIND GENeration program (WINDGEN) are automatically accessed and retireved. In addition, wind/wave validation data from NDBC (National Data Buoy Center) and water level/tide data from NOS (National Ocean Service) are being ingested in real time. All scripts have been running throughout the hurricane season and are robust and stable and keep performing well. The WINDGEN program can input either H*WIND analysis or perform its own wind field generation using the TC96 tropical boundary model. The program also provides wind/pressure output for numerous alternate track models for use by the modelers. Numerous upgrades were made to the WINDGEN software during the 2004/2005 period. Native ADCIRC output is now built into the model. This integration not only saves time during the forecast run, but also makes use of WINDGEN's space interpolation routines to better describe the stress and pressure inputs on the ADCIRC grid. The surge modelers can easily apply updates to the ADCIRC output as new grids/domains are tested and brought online into the operational system. As a result of post-analysis work done on Hurricane Ivan 2004, the blending of the H*WIND/TC96 into the GFS background field has been adjusted. This results in wind fields that better blend into the synoptic flow. Additional work on the WINDGEN code involved the handling of bad/erroneous winds data and better failover if bad data is encountered. The latest version of WINDGEN is run operationally on GERONIMO at 0.2 degree and SATANTA at 0.1 degree currently for post-storm analyses. Figure 1 shows an example of the wind field product available from the NOPP project.

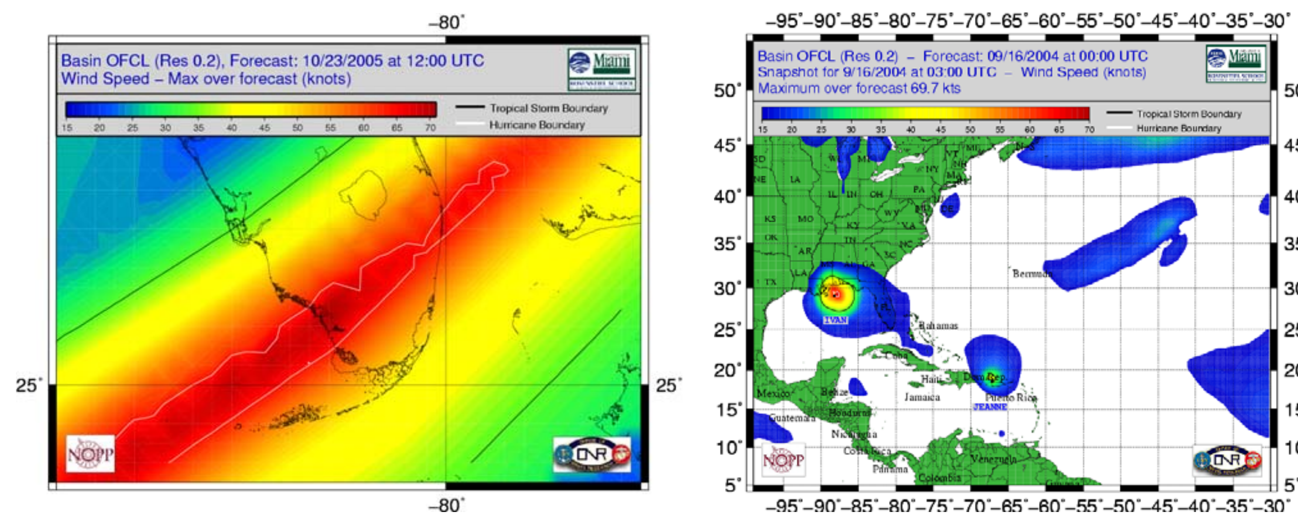

Figure 1: Wind fields generated by WINGEN during the 2004 Hurricane season. Left: Zoomed in graphics of wind field associated with Hurricane Wilma near landfall. The black boundary shows the extent of tropical force winds while the white line shows the region of hurricane force winds. Right: Wind fields associated with tropical storm in the NOPP basin grid. The plot shows Hurricanes Ivan and Jeanne. Only winds in excess of 15 kts are shown to minimize clutter and maintain focus on storm dynamics.

Wave Modeling:

A fully tested and automated, operational wave forecasting system based on WAM Cycle 4.5 for Hurricanes at Landfall was put in place for the 2004 Hurricane season. The 2005 Hurricane season demonstrated how robust and stable WAM performed and the quality of the wave forecasts. This was made possible by significant improvements internal to the model which led to revisions to source term specification that constrained wave growth consistent with recent behavior of the drag coefficient as the surface condition goes from aerodynamically smooth (characterized by a drop in the drag coefficient with increasing wind) to aerodynamically rough (drag coefficient increasing with wind speed), multi-grid nesting, ice coverage implementation and more importantly depth limited breaking. In addition the model has been optimized for scalable computational platforms reducing the operational constraints by a factor of 20. These improvements, and three years of critical evaluation for the 2003 through the 2005 hurricane season by the NOPP project that included many historical tropical storm simulations produced a wave model with unprecedented performance characteristics. The latter implementation and execution provided insights into improvements in the source terms reducing significant errors in the core of tropical systems by 30-percent. Figure 2 shows two examples of wave height predictions for the active 2004 Hurricane season. These products are typically generated and available on the NOPP project website.

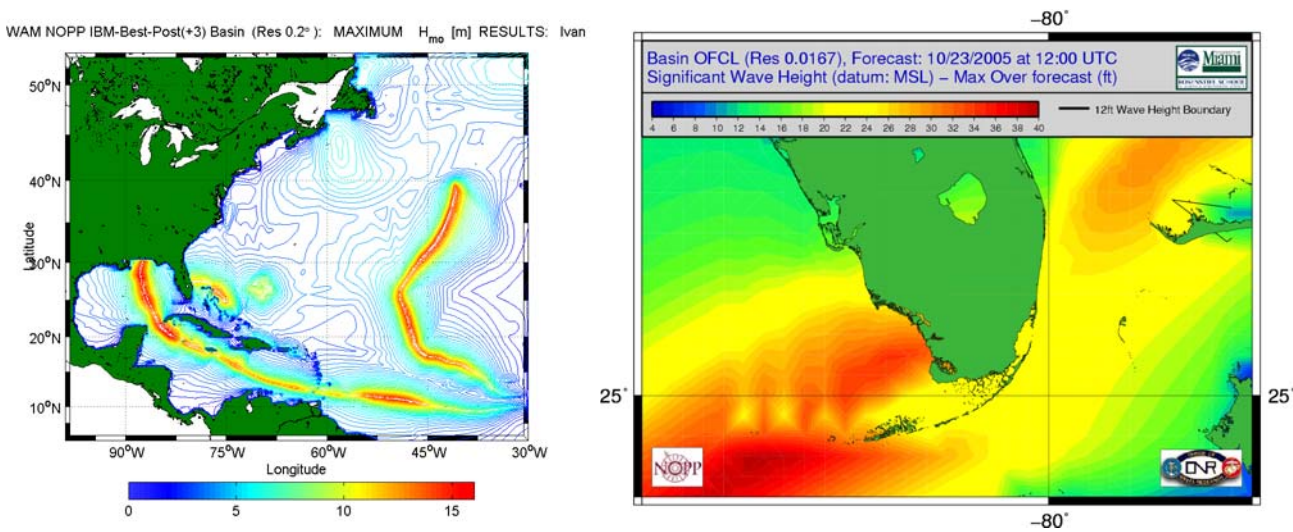

Figure 2: Left: Basin scale wave forecast for Hurricane Ivan. The results show the maximum wave heights associated with Hurricane Ivan. Clearly visible are the different stages of intensification and weakening as Ivan moved through the Caribbean Basin and into the Gulf of Mexico. During Ivan's lifecycle Hurricanes Frances and Karl were also present in the Atlantic Basin while Jeanne was just gaining intensity east of the Bahamas. Right: Zoomed in wave height predictions of Hurricane Wilma shortly before landfall for a five day forecast cycle commencing on October 23, 2005 at 12:00 UTC. Maximum wave height conditions associated with Wilma appear to reach nearly 40 ft in the Florida Strait .

Surge Modeling: We have now fully integrated the ADCIRC (Advanced Circulation Model for Coasts, Shelves and Estuaries) with the WAM Cycle-4.5 model to improve predictive skill for storm surge during tropical cyclones. In addition to the standard ADCIRC implementation, we are also running a parallel version (PADCIRC) to achieve more efficient processing for the alternate track ensemble. Both ARCIRC versions have been optimized and include the effects of wave through the radiation stress provided by the WAM model. Additional improvements were made by establishing an operational mesh with a minimal number of computational points (47,860, hereto referred as the 48K mesh) that produces highly accurate astronomical tide simulation results. Figure 3 displays the 48K mesh for the domain which encompasses the Gulf of Mexico, Caribbean Sea, and the northern portion of the Atlantic Ocean found west of the 60° west meridian. The open ocean boundary extends from the area of Glace Bay, Nova Scotia, Canada to the vicinity of Corocora Island in eastern Venezuela. Due to the vast size of the WNAT model domain (8.347 x 10^6 km^2) and because of the high resolution required to accurately represent irregular coastline geometries and rapidly varying bathymetric gradients within the computational domain, it is clearly beneficial to employ an unstructured finite element mesh for tidal computations. Spatial resolution of the mesh ranges from a node spacing of approximately 160 km in the Atlantic Ocean to roughly 6 km element sizes along the coastal boundaries. This mesh can be employed in astronomic and meteorological tidal simulations with a time step of 30 seconds, permitting a five day forecast to be completed on the IBM computing system in less than 10 minutes. Figure 3 also shows two examples of the tidal predictions compared to historical observations.

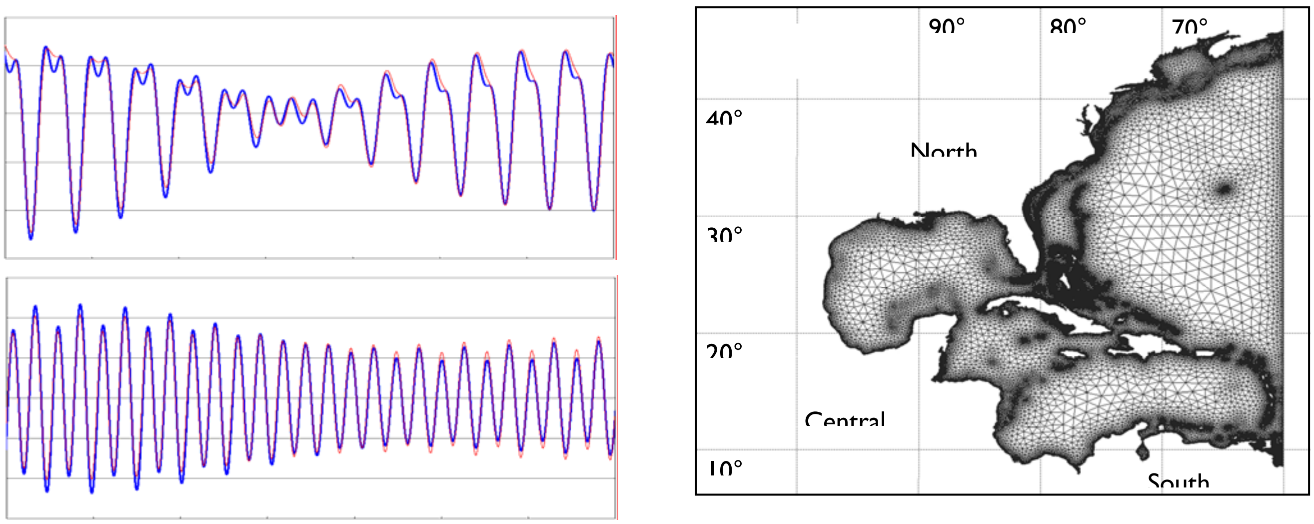

Figure 3: Left: A re-synthesis of historical and modeled tidal constituents for a complete spring and neap tidal cycle at selected stations. These tidal predictions are used to compute the full storm tide water level changes during storm surge events when hurricanes make landfall. Right: Operational mesh for storm tide simulations as implemented for the NOPP forecast system.

Figure 4 shows two examples of the maximum predicted storm surge over a 5-day forecast cycle for Hurricanes Katrina and Wilma. The forecasted conditions were pretty close to the observed water level changes during these storms.

IMPACT/APPLICATIONS

An improved forecast of the coastal environment under hurricane conditions has potential benefit for society in several areas. A primary benefit is the early warning and evacuation of population and mobile assets from threatened coastal areas. The storm surge modeling can also be extended to include tsunami prediction and warning capabilities.

National Security

Improved forecasting of several days in advance will help emergency planners and FEMA as well as DHS to prepare adequately for approaching tropical cyclones.

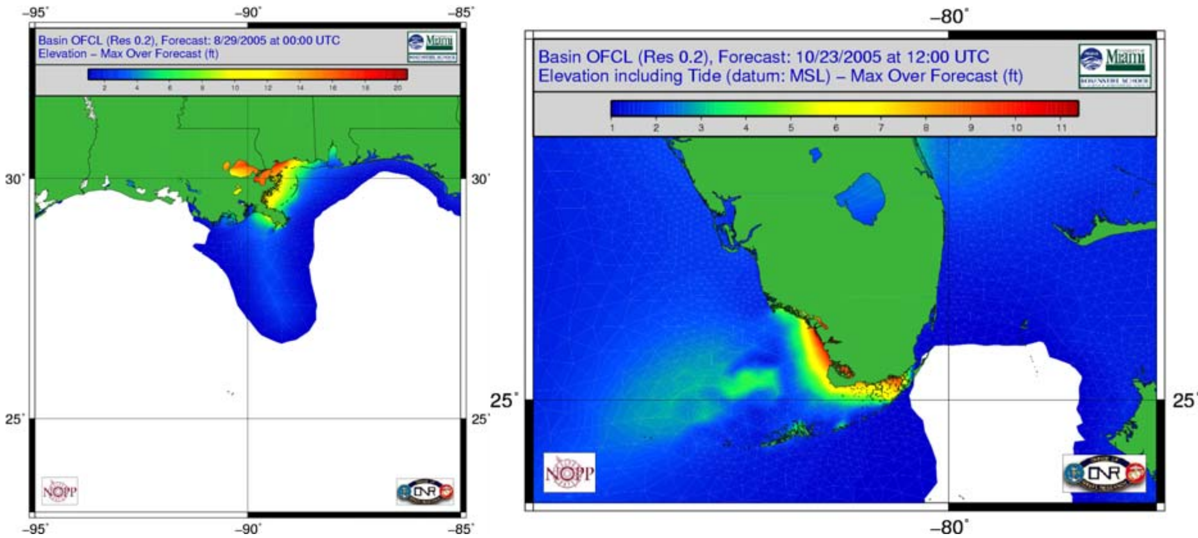

Figure 4: Maximum storm surge levels for Hurricanes Katrina (left) and Wilma (right) over a five day forecast cycle along the official track as provided by the National Hurricane Center.

Economic Development
This forecast system could also be used to determine which coastal regions are extremely vulnerable to the impact of tropical cyclones especially caused by flooding and wave damage. New risk and exposure maps for flooding can readily be generated with the added benefit of risk factors, i.e. not all storm may lead to flooding.

Quality of Life
Understanding better the risk to potential damage will allow the public and communities to make decisions on where to live and how to manage coastal and ecological resources.

Science Education and Communication
Assessment of operational models will identify shortcomings in the science and physics of models used for weather prediction as well as the need for the right data at critical locations and times.

TRANSITIONS

National Security
We are exploring to implement the system at the Joint Typhoon Warning Center in Hawaii to cover the Pacific Ocean especially the western portion of the Pacific.

RELATED PROJECTS

This NOPP project began to partner with SCOOP whose primary goal is to provide high-resolution storm surge predictions during severe weather phenomena such as tropical and extra-tropical storms in coastal regions along the US East coast and Gulf of Mexico. To achieve this goal SCOOP will utilize the NOPP's coupled model forecast system. Two studies started that target specific coastal and inland regions. First, a study with the NWS Southeast River Forecast Center to produce real-time tides and storm tide hydrographs for the Waccamaw River region in South Carolina. In addition, NOAA, through the NWS Office for Hydrologic Development has funded a three-year. A collaborative effort between UCF and UF led to a pilot study for the Florida Department of Transportation (FDOT), which will examine the effects that inlet shapes, as well as coupled short and long wave models have on nearshore storm tide hydrographs that are then employed in bridge scour studies.

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